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An Improved Brane Anti-Brane Action from Boundary Superstring Field Theory and Multi-Vortex Solutions Nicholas T. Jones and S.-H. Henry Tye

We present an improved effective action for the D-brane-anti-D-brane system obtained from boundary superstring field theory. Although the action looks highly non-trivial, it has simple explicit multi-vortex (i.e. codimension-2 multi-BPS D-brane) multi-anti-vortex solutions. The solutions have a curious degeneracy corresponding to different "magnetic" fluxes at the core of each vortex. We also generalize the brane anti-brane effective action that is suitable for the study of the inflationary scenario and the production of defects in the early universe. We show that when a brane and anti-brane are distantly separated, although the system is classically stable it can decay via quantum tunneling through the barrier.

D-Branes; Tachyon Condenstaion; String Theory; Brane-World Cosmology
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Introduction D-branes play a crucial role in string theory Polchinski:1998rq. To understand the D-brane anti-D-brane ($D\bar{D}$) system involves off-shell physics. A powerful way to study it is to write down its effective space-time action from background-independent or boundary string field theory (BSFT) Witten:1992qy, Shatashvili:1993kk, Kutasov:2000qp. Following the work on the non-BPS D-brane effective action in open superstring theory Kutasov:2000aq, this program was carried out by two groups (KL Kraus:2000nj and TTU Takayanagi:2000rz). Here we seek to improve on their effective $D\bar{D}$ action and study its properties.

The effective action in RefsKraus:2000nj, Takayanagi:2000rz has a number of interesting properties. It includes all powers of the single derivative of the tachyon field T, a feature very important for time dependent, or rolling tachyon, solutions Sen:2002nu, Sugimoto:2002fp. This feature is also necessary to lead to the fact that the lower dimensional branes appear as soliton solutions in tachyon condensation. In particular, KL/TTU find a codimension-two BPS brane as a solitonic solution, with the correct brane tension and the correct RR charge Sen:1999mg, Witten:1998cd, Horava:1998jy. However, that vortex solution does not have "magnetic" flux inside it, contrary to our intuition from the Abelian Higgs model. As written, the KL/TTU effective action that involves all powers of the first derivative of T does not respect the $U(1) \times U(1)$ gauge symmetry of the $D\bar{D}$ system; the derivatives of T do not generalize to covariant derivatives, as is necessary since the complex tachyon field T is charged under the relative $U(1)$. Without the correct gauge covariant action, it is not clear whether the vortex solution, and more generally the multi-vortex solutions, should have "magnetic" flux inside them or not.

We improve the $D\bar{D}$ effective action by restoring the covariance and the $U(1) \times U(1)$ gauge symmetry of the system so the tachyon field couples to one of the gauge fields as expected. This improved action is summarized in Eq.(action). Starting with this $D\bar{D}$ action we find analytic multi-vortex multi-anti-vortex solutions (all parallel with arbitrary positions and constant velocities), summarized in Eq.(general$_s$olution).$The solution with n vortices (i$ 2$branes) and m anti-vortices has total tension \varepsilon_{p-2} = (n+m)\tau_{p-2}$ and Ramond-Ramond (RR) charge $\mu_{p-2} = (n-m)\tau_{p-2}g_s$ under the spacetime $(p-1)$-form potential. Here τ_{p-2} is the D$(p-2)$-brane tension and g_s is the string coupling constant. The simplicity of the solution suggests that the $D\bar{D}$ effective action may be useful to study the brane dynamics. For $m = 0$ and an appropriate choice of the magnetic flux, the solution is supersymmetric and corresponds to n BPS D$(p-2)$-branes.

These solutions have a curious degeneracy. Each unit of winding (i.e. a vortex corresponding to a D-brane) can have up to one unit of "magnetic" flux inside it. That is, both the tension and the RR charge are independent of the presence (or absence) of the "magnetic" flux. We expect this degeneracy to be lifted by the quantum corrections to the $D\bar{D}$ action and/or the corrections from the higher derivative and gauge field-strength terms. However, it is not clear exactly how the degeneracy will be lifted.

One motivation to understand the $D\bar{D}$ system better is its role in cosmology. D-brane interaction in the brane world scenario provides a natural setting for an inflationary epoch in the early universe Dvali:1998pa, Burgess:2001fx, Garcia-Bellido:2001ky, Jones:2002cv. There, the inflaton is simply the brane-brane separation while the inflaton potential comes from their interaction. The simplest such scenario involves a

brane-anti-brane pairDvali:2001fw, Burgess:2001fx, Alexander:2001ks. Toward the end of inflation, as the brane and the anti-brane approach each other and collide, a tachyon emerges and tachyon condensation (i.e. the tachyon field rolling down its potential) is expected to reheat the universe and produce solitons (even codimensional branes) that appear as cosmic strings in our universe Jones:2002cv. The cosmic string density is estimated to be compatible with present day observations, but will be critically tested by cosmic microwave background radiation and gravitational wave detectors in the near futureSarangi:2002yt. To study inflation and how it ends, we also construct the $(D\bar{D})_p$ effective action when the brane is separated from the anti-brane. We find a separation dependent tachyon potential which predicts that the $D\bar{D}$ system is classically stable when the brane and anti-brane are further than $2\pi^2\alpha' 2\ln 2$ apart, but can quantum mechanically decay with the tachyon tunneling through its potential. The critical separation agrees with the result known from other methods Banks:1995ch aside from the factor of $2\ln 2$.

The paper is organized as follows. In §2, we briefly review the BSFT derivation of the $D\bar{D}$ action. Then we use Lorentz and gauge symmetry to complete the terms in the effective action. As a check, we expand it to next to leading order and show agreement with known results. In §3, we present the general multi-vortex multi-anti-vortex solutions, with zero and non-zero gauge field strengths inside the vortices. We calculate the RR charge and the total energy of these solutions and reveal the degeneracy. We discuss how this degeneracy may be lifted. In §4, we construct the effective action when the Dp-brane and the $\bar{D}p$-brane are separated. The barrier potential to tunelling is evaluated. §5 is the conclusion.

Brane Anti-Brane Effective Actions Linear Tachyon Action from BSFT We summarize the brane anti-brane effective action from BSFT calculated by KL and TTU Kraus:2000nj,Takayanagi:2000rz. We restrict attention to D9-branes in type IIB theory, and generalize using T-Duality later. BSFT essentially extends the sigma-model approach to string theoryTseytlin:1989rr, in that (under certain conditions Witten:1992qy, Kutasov:2000qp) the disc world-sheet partition function with appropriate boundary insertions gives the classical spacetime action. This framework for the bosonic BSFT was extended to the open superstring in Kutasov:2000aq and formally justified in Marino:2001qc. In the NS sector the spacetime action is aligndefinition$_S S_{spacetime} = -\int DXD\psi D\tilde{\psi}\, e^{-S_\Sigma - S_{\partial\Sigma}}$.